AD 823762

AD

TECHNICAL REPORT ECOM-00013-66

NONPERPENDICULAR ILLUMINATION OF ULTRASONIC CELLS

Report of Project MICHIGAN

By

EDWIN E. HENRY

HARVEY RING

19961212 113

August 1966

ECOM

UNITED STATES ARMY ELECTRONICS COMMAND · FORT MONMOUTH, N.J.

Contract DA-28-043 AMC-00013(E)

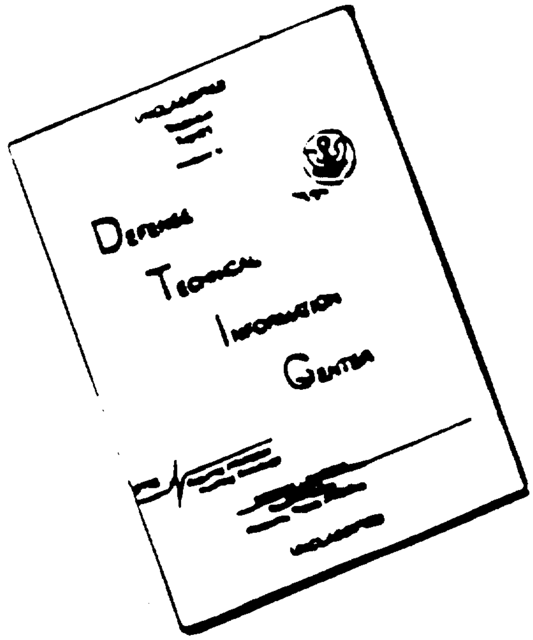
Willow Run Laboratories

THE INSTITUTE OF SCIENCE AND TECHNOLOGY

The University of Michigan Ann Arbor, Michigan

Distribution of this document is unlimited.

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

NOTICES

Sponsorship. The work reported herein was conducted by the Willow Run Laboratories of the Institute of Science and Technology for the U. S. Army Electronics Command under Project MICHIGAN, Contract DA-28-043-AMC-00013(E) (continuation of Contracts DA-36-039-SC-78801 and DA-36-039-SC-52654), and for the U. S. Air Force under Contract AF 33(615)-1452. Contracts and grants to The University of Michigan for the support of sponsored research are administered through the Office of the Vice-President for Research.

Disclaimers. The findings of this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

The citation of trade names and names of manufacturers in this report is not to be construed as official Government indorsement or approval of commercial products or services referenced herein.

Disposition. Destroy this report when it is no longer needed. Do not return it to the originator.

TECHNICAL REPORT ECOM-00013-66 AUGUST 1966

NONPERPENDICULAR ILLUMINATION OF ULTRASONIC CELLS

Report of Project MICHIGAN
CONTRACT NO. DA-28-043-AMC-00013(E)
DA Project 1P6 20801 A 175 05

By

EDWIN E. HENRY
HARVEY RING

Radar and Optics Laboratory
Willow Run Laboratories
THE INSTITUTE OF SCIENCE AND TECHNOLOGY
THE UNIVERSITY OF MICHIGAN
Ann Arbor, Michigan

For

U. S. ARMY ELECTRONICS COMMAND, FORT MONMOUTH, N. J.

Distribution of this document is unlimited.

ABSTRACT

Results obtained by nonperpendicular illumination of ultrasonic cells are described. There is reasonably good agreement between theory and experiment; this agreement exists for results obtained when the cell is operated at 5, 15, and 25 Mc/s. In an optical analog computer, the light intensity of the optical output can be increased considerably by illuminating the cell at the Bragg angle; but this increase is obtained at the expense of decreased bandwidth of operation.

ULTRASONIC RADIATION

end

FOREWORD

In accordance with recommendations of Project TEOTA (The Eyes of the Army), a large technical study made by the Army in 1952 on the problems of combat surveillance, Project MICHIGAN was established in May 1953 under a tri-service charter and under a contract administered by the U. S. Army Signal Corps. Its purpose was to perform research and development encompassing all problems pertaining to combat surveillance. The Project MICHIGAN contract essentially left the determination of the program to the Project itself. The Project was to determine the nature of the problems, the needs of the services, and the way the physical sciences could be used to meet these needs. A joint-services tactical and technical steering committee was established to provide broad guidance.

During the summer of 1953, Project MICHIGAN convened Project WOLVERINE, a summer study program to review the problems of combat surveillance and to recommend an initial program for Project MICHIGAN.

In February 1957, the U. S. Army Combat Surveillance Agency (USACSA) was established. At about this time, the tri-service charter and steering committee were terminated, and guidance of the project was assigned to USACSA. USACSA defined the role of Project MICHIGAN as complementary to the functions of the U. S. Army Signal Research and Development Laboratories and the U. S. Army Electronic Proving Ground. The "mission" of Project MICHIGAN has since been defined as follows: "To conduct a continuing long-range research and development program for advancing the Army's combat-surveillance and target-acquisition capabilities." With the reorganization of the Army in mid-1962, the technical cognizance of Project MICHIGAN shifted from the Office of the Chief Signal Officer to the U. S. Army Materiel Command (USAMC). Currently, technical guidance is provided by the Combat Surveillance and Target Acquisition Laboratory of the U. S. Army Electronics Command for USAMC.

The research and development effort of Project MICHIGAN is oriented toward achieving new and improved techniques which will lead to new or greatly improved combat-surveillance and target-acquisition equipment that will meet the long-range operational requirements of the Army in the field. Since 1953, the work of Project MICHIGAN has been concerned primarily with theoretical and experimental investigations to determine and to demonstrate the potential value of the many concepts and ideas for combat surveillance and target acquisition brought out in TEOTA and WOLVERINE and subsequently proposed by others including the Project itself. The cur-

rent emphasis is on the subjects of imaging radar, hologram radar, MTI radar, infrared-optical imaging and signal correlation techniques, and image interpretation.

The work reported upon was conducted under Subproject 1, Task 1, of the overall technical program for Project MICHIGAN approved by the Contracting Officer's Technical Representative under DA Project Number 1P6 20801 A 175, Task 05, "Airborne Surveillance Target Acquisition Radar Receiver, Recording and Display Techniques."

The Project is a part of a diversified program of research conducted for the Willow Run Laboratories of The University of Michigan's Institute of Science and Technology by a full-time staff of specialists in physics, engineering, mathematics, and related fields, by members of the teaching faculty, by graduate students, and by other research groups and laboratories of The University of Michigan. The function of the Institute of Science and Technology is to make available to government and industry the resources of The University of Michigan and to broaden the educational opportunities for students in the scientific and engineering disciplines.

The computations described in this report were performed by Mr. George Hurchalla and Mr. David B. Kirk of the Computation Department of the Willow Run Laboratories.

Progress and results described in reports are continually reassessed by Project MICHIGAN. Comments and suggestions from readers are invited.

CONTENTS

FIGURES

NONPERPENDICULAR ILLUMINATION OF ULTRASONIC CELLS

1. INTRODUCTION

The ultrasonic cell has long been used as a device for introducing a given input function into an optical analog computer for such purposes as spectrum analysis, filtering, and optical scanning. Modern technology has demanded more and more bandwidth in such devices, which, in turn, require the use of transducers with higher and higher resonant frequency. However, it has been shown [1] that at the higher frequencies the intensity of the desired optical output of such a computer decreases rapidly (with frequency) when the cell is illuminated with light which is perpendicular to the ultrasonic wave train. One possible solution to the problem of increasing the intensity of the output is to illuminate the cell at the Bragg angle, that angle at which all rays emitting from the cell are in phase.

2. THEORETICAL RESULTS

Figure 1 shows a general optical schematic in which collimated light is directed toward an ultrasonic cell of thickness L and length d. The ultrasound creates a phase grating in the cell, the Fourier transform of which is formed by the objective lens when the light is incident perpendicular to the ultrasonic wave train. The intensity of the light forming the central image I_0 (zero frequency), first-order images I_1 and I_1' (fundamental frequency), and higher harmonic images, all of which occur in a plane located a focal distance behind the objective lens, indicates the strength of these harmonics in the exciting signal.

Raman and Nath [2] performed one of the first analyses of the case in which the light is perpendicular to the ultrasonic wave train. By evaluating the diffraction integral across the face of the cell they found that the spectral images occur at an angle

$$\theta = \frac{n\lambda}{\lambda^*} \tag{1}$$

where θ = angle of inclination from the center line of the optical system

n = order of the harmonic frequency

λ = wavelength of the light

λ^* = wavelength of the ultrasound in the delay medium

and that the images have an intensity

$$\frac{I_n}{I_m} = \frac{J_n^2(v_t)}{J_m^2(v_t)} \tag{2}$$

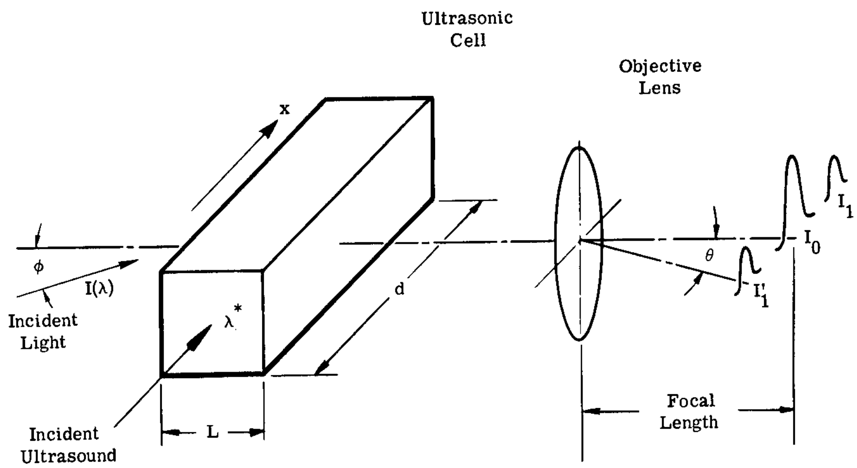


FIGURE 1. OPTICAL SCHEMATIC

where I_n = intensity of the nth harmonic

I_m = intensity of the mth harmonic

J_n and J_m = Bessel functions of the nth and mth orders

$$v_t = \frac{2\pi\mu L}{\lambda} \tag{3}$$

μ = alternating portion of the index of refraction

The above relations describe what is known as normal diffraction, i.e., diffraction in which the ultrasonic wavelength is long, and the value of μ is small.

Willard [3] has expressed a criterion for distinguishing normal from abnormal diffraction. He suggested that the value of the product

$$K = \frac{Lf^2 v_t}{2\pi} \tag{4}$$

where f = acoustic frequency of operation

provides a working distinction between normal and abnormal Bragg diffraction. He used the value 34.4 Mc/s^2-cm as a criterion. If K is less than this number, the diffraction is normal; but if K is greater, the diffraction is abnormal. In common practice, the use of 10 Mc/s or less results in normal diffraction; the use of more than 10 Mc/s results in abnormal diffraction. Abnormal diffraction occurs when I_1 and I_1' (fig. 1) do not occur simultaneously with equal strength. Hargrove [4], and other investigators, considered the abnormal cell as a series of normal cells. He introduced the parameters

$$Q_\ell = \frac{2\pi\lambda\ell}{\mu_\lambda^{*2}} \qquad \text{and} \qquad V_\ell = \frac{2\pi\mu\ell}{\lambda} \tag{5}$$

where Q_ℓ = a constant for the individual layer

ℓ = thickness of the individual layer

μ_0 = index of refraction

V_ℓ = the incremental phase change in the individual layer

and stated that $Q_\ell V_\ell << 2$ for normal diffraction.

Klein [5] achieved a considerable simplification of Hargrove's results and, among others, used the parameter

$$\alpha = -\mu_0 \frac{\lambda^*}{\lambda} \sin \phi \tag{6}$$

where α = an angular constant

ϕ = angle of incidence measured from the normal

A value of $\alpha = \frac{1}{2}$ is equivalent to the Bragg angle.

The program, as defined by Klein, was set up for the IBM-7090 computer to obtain theoretical predictions which could be compared with experimental results obtained earlier. During the computation, a most interesting phenomenon was noted; namely, that when the ultrasonic cell was illuminated at the Bragg angle, the ratio of I_1/I_0 was independent of frequency. This result, which is shown in figure 2, was also noted and experimentally verified by Klein [6].

3. EXPERIMENTAL PROGRAM

3.1. EQUIPMENT USED

The optical arrangement for the experimental program is shown in figure 3. A filtered 5461-Å lamp was used as a light source. A set of 75-mm, f/2.8 lenses was used as a condenser. The output of the last lens was focused on a 25-μ-diam aperture, thus simulating a point source, the output of which was collimated by a 100-mm, f/2.3 lens. The output from this lens constituted the incident light $I(\lambda)$ of figure 1. The angle of illumination was varied by changing the position of the light-source section, shown mounted on a wooden platform in the figure, and was calculated from the dial-gauge reading.

The faces of the ultrasonic cell were of optical-quality glass, polished flat to 1/8 wavelength. The internal dimensions of the cell were 7/8 × 7/8 × 2-in long. A rubber ultrasound absorber was cemented to the end of the cell opposite the transducer.

All transducers were X-cut quartz crystals. Most were 1/2-in in diameter, with a 3/8-in-diam gold electrode evaporated on one side and a 1/2-in-diam gold electrode evaporated on the other side. However, some crystals were smaller in diameter.

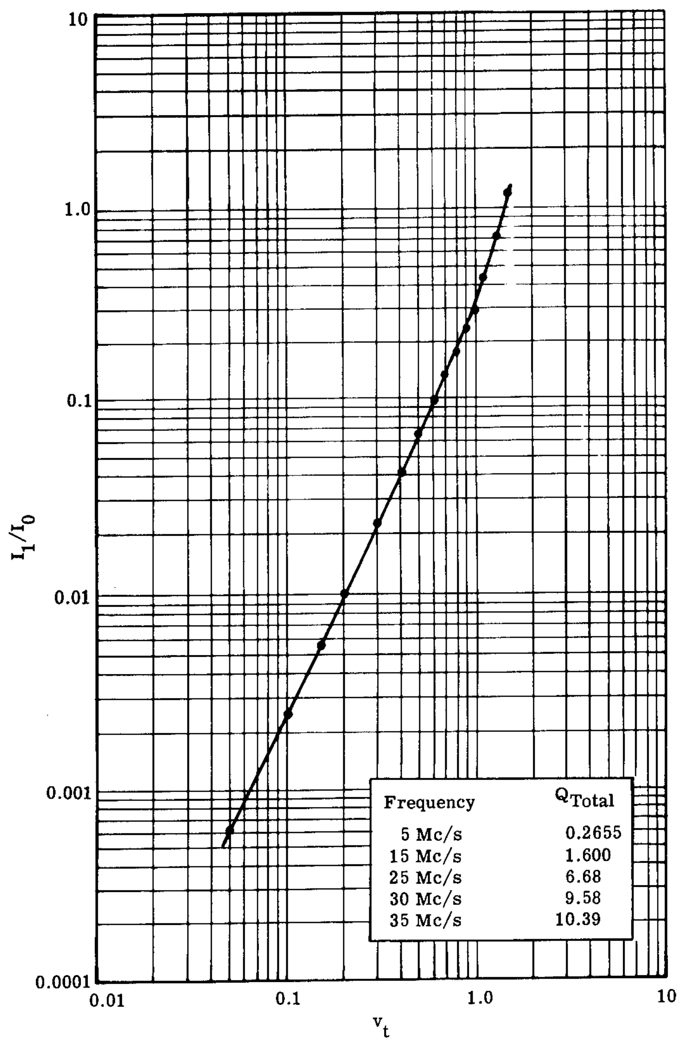


FIGURE 2. BRAGG-ANGLE ILLUMINATION OF ULTRASONIC CELLS ($\alpha = 1/2$)

Crystals with fundamental resonant frequencies of 5, 15, and 25 Mc/s were used. The crystals were mounted onto a plastic holder which had a 3/8-in hole drilled so that the inner electrode was accessible for electrical connection; therefore, the backing impedance of the crystals was air.

The light beam was directed through the ultrasonic column, far enough from the transducer to avoid local transducer disturbances, but close enough to minimize ultrasonic attenuation losses. Then the optical output from the ultrasonic cell was brought to a focus with a 152-mm, f/2.7 lens. Finally, the intensity of the spectral images was measured with a specially constructed and dc-operated photomultiplier circuit which has shown excellent stability.

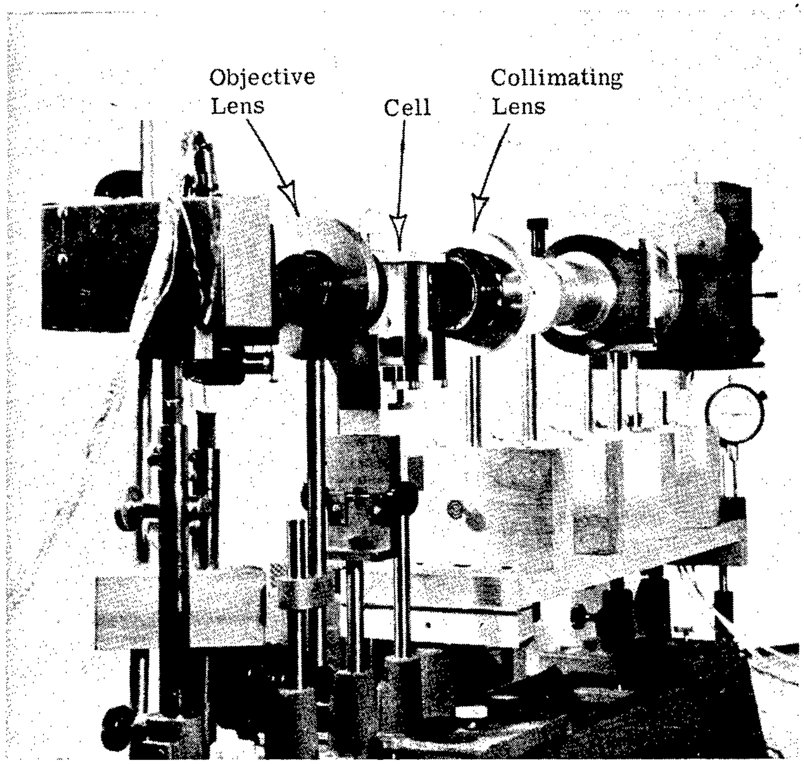
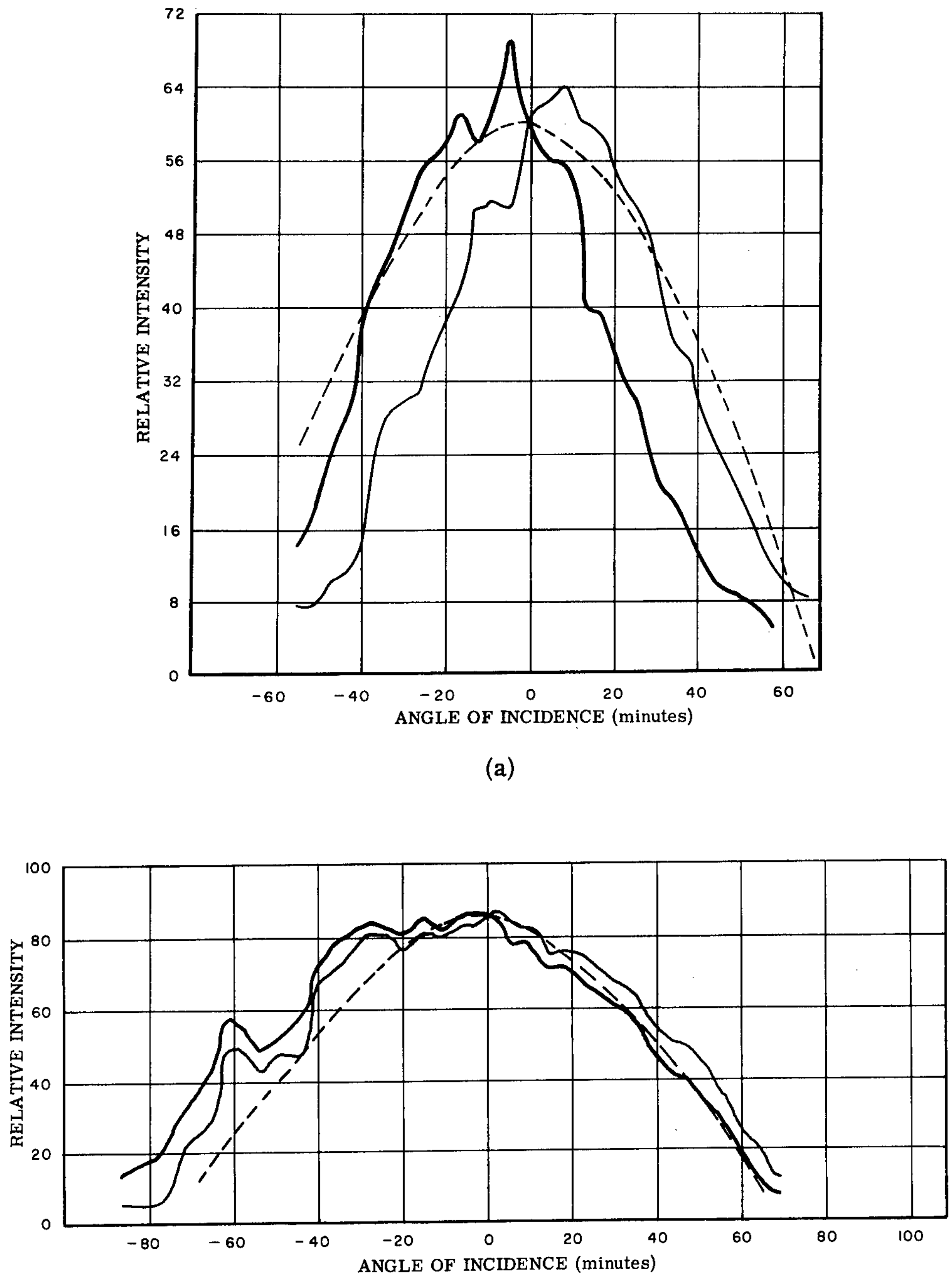


FIGURE 3. ARRANGEMENT OF OPTICAL EQUIPMENT

3.2. EXPERIMENTAL RESULTS

The experimental results are given in figures 4 through 6, which show the relative intensity of the first-order diffraction image as a function of the angle of incidence. In these figures, three curves are shown: The heavier line is the intensity of one first-order image (I_1 in fig. 1), the lighter line is the intensity of the other first-order image (I_1' in fig. 1), and the broken line is the computed result for I_1. Figure 4 shows the results for a transducer with a resonant frequency of 5 Mc/s, figure 5 shows the results for 15 Mc/s, and figure 6 shows the results for 25 Mc/s.

One result which is immediately evident from these tests is that, at 25 Mc/s and, undoubtedly, at higher frequencies, considerably more light is available when the cell is illuminated at the Bragg angle than when it is illuminated at an angle perpendicular to the ultrasonic wave train (the angle at which the two curves I_1 and I_1' intersect).



(a)

(b)

FIGURE 4. RELATIVE INTENSITY OF FIRST-ORDER DIFFRACTION VS. ANGLE OF INCIDENCE FOR OPERATION AT 5 Mc/s. (a) 60 V. (b) 100 V.

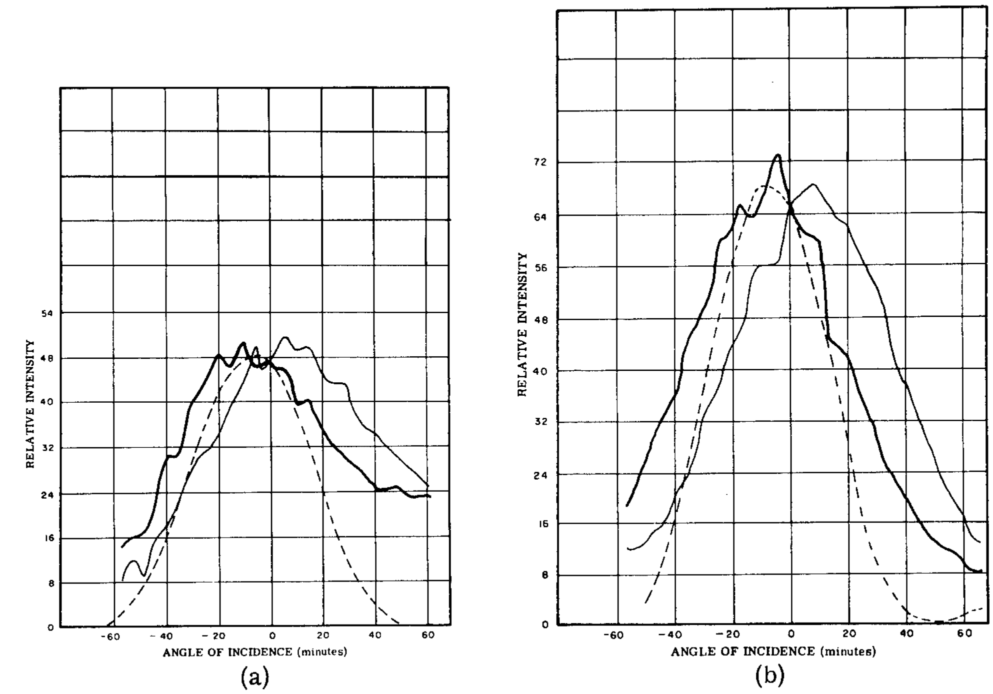


FIGURE 5. RELATIVE INTENSITY OF FIRST-ORDER DIFFRACTION VS. ANGLE OF INCIDENCE FOR OPERATION AT 15 Mc/s. (a) 40 V. (b) 60 V.

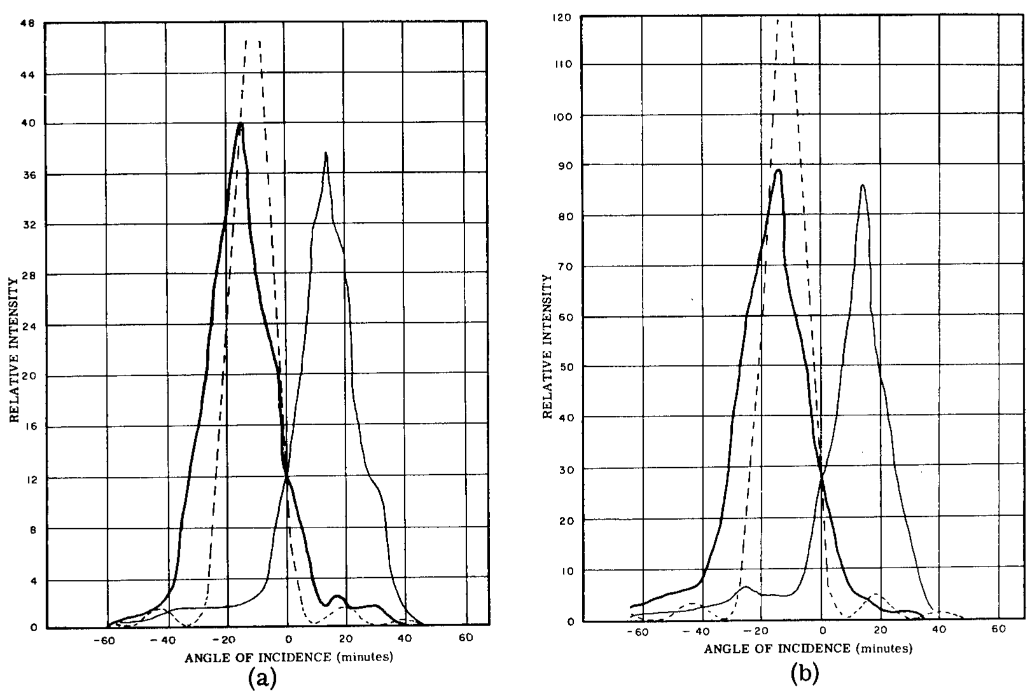


FIGURE 6. RELATIVE INTENSITY OF FIRST-ORDER DIFFRACTION VS. ANGLE OF INCIDENCE FOR OPERATION AT 25 Mc/s. (a) 30 V. (b) 50 V.

4. DETERMINING THE THEORETICAL-RESULTS CURVES

The theoretical results, shown by the broken line in figures 4 through 6, were computed in the following manner: The computer program for the theoretical solution was defined by three parameters, v_t (eq. 3), Q (eq. 5), and α (eq. 6). In essence, we specified a value of v_t, which gives the driving voltage; a value of Q, which essentially gives the operating frequency (for a specific ultrasonic cell); and a value of α, which gives the angle of illumination, once the other operating conditions are established.

An experimental curve, in which I_1/I_0 was plotted as a function of electrical voltage, was determined, with the ultrasonic wave train perpendicular to the light beam ($\alpha = 0$). And a theoretical curve in which I_1/I_0 was plotted as a function of v_t was determined ($\alpha = 0$). Then, by matching values of I_1/I_0 from the two curves, an operating value of v_t was determined. (In the latter curve, the value of Q was adjusted for the cell dimensions and operating frequency of the experimental curve.) Using the operating value of v_t, we determined a theoretical curve in which I_1/I_0 was plotted as a function of α, and we adjusted the intensity value of the curve, where $\alpha = 0$, to indicate the theoretical relative intensity at other angles of illumination. This information was then plotted as the broken line shown in figures 4 through 6.

5. DISCUSSION OF RESULTS

A comparison of the computed curve with the experimentally obtained curves (figs. 4 through 6) indicates that good agreement exists between theory and experiment, with the possible exception of the results at 25 Mc/s; here, the theoretical intensity far exceeds the experimental intensity. It is believed that this discrepancy was caused by experimental error. However, there is a much more important aspect of these results which should be discussed: that aspect is the ratio of light intensity obtained when the cell is illuminated at the Bragg angle to the intensity obtained when the cell is illuminated perpendicularly to the ultrasonic wave train. Further, the effects of these two types of illumination on the bandwidth that may be achieved under the same conditions must be considered. From table I, it is obvious that at frequencies below 25 Mc/s (Q = 6.68), there is little to be gained in light intensity by illuminating at the Bragg angle.

Let us now consider the bandwidth available. This may be calculated from the expression

$$\alpha = -\mu_0 \frac{\lambda^*}{\lambda} \sin \phi$$

from which

$$\Delta\alpha = -\mu_0 \frac{\Delta\lambda^*}{\lambda} \sin \phi$$

TABLE I. COMPUTED I_1/I_0 FOR ILLUMINATION AT BRAGG ANGLE COMPARED WITH COMPUTED I_1/I_0 FOR ILLUMINATION PERPENDICULAR TO WAVE TRAIN

Frequency (Mc/s)	Voltage (rms)	I_1/I_0 for Illumination at Bragg Angle (A)	I_1/I_0 for Illumination Perpendicular to Wave Train (B)	Ratio $\left(\frac{A}{B}\right)$
5	60	0.0447	0.0449	1.0
5	100	0.1119	0.1120	1.0
15	40	0.0237	0.0225	1.05
15	50	0.0333	0.0317	1.05
15	60	0.0459	0.0437	1.05
25	30	0.42	0.109	3.85
25	40	0.712	0.149	4.76
25	50	0.999	0.166	6.03

From the computed data, $\Delta\alpha$, $\Delta\lambda^*$, and the bandwidth can be determined. Since light intensity is analogous to power, the available bandwidth can be determined as that difference in ultrasonic wavelength which produces a change in α sufficient to decrease the value of I_1 to 0.5 of I_1 when $\alpha = 0$ (see table II).

It is easily seen that the increase of usable light achieved by illuminating at the Bragg angle is obtained at the cost of drastically decreasing the available bandwidth. This decrease in bandwidth is independent of that which usually occurs because of difficulties inherent with crystal transducers. However, it should be borne in mind that these bandwidth results are calculated

TABLE II. AVAILABLE BANDWIDTH WHEN ILLUMINATING AT THE BRAGG ANGLE (0.500 criterion)

Frequency (Mc/s)	Band Limits: f_1 to f_2* (Mc/s)	Bandwidth (Mc/s)
15	11.12 to 23.1	11.98
25	23.4 to 26.8	3.4

*$f_1 < f_0 < f_2$ where f_1 = lower band limit

f_0 = resonant frequency

f_2 = upper band limit

and have not been verified experimentally. Nevertheless, since there has been excellent theoretical-experimental agreement throughout the program, it is felt that these conclusions bear merit.

REFERENCES

1. E. E. Henry and H. M. Ring, Higher Frequency Ultrasonic Light Modulators, Report No. 6400-54-T, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, November 1965.
2. C. V. Raman and N. J. Nath, "Diffraction of Light by HF Sound Waves," Proc. Indian Acad. Sci., Vol. 2, 1935, pp. 406-409.
3. G. W. Willard, "Criteria for Normal and Abnormal Light Diffraction Effects," J. Acoust. Soc. Am., Vol. 21, 1949, pp. 101-108.
4. L. E. Hargrove, "Optical Effects of Ultrasonic Waves Producing Phase and Amplitude Modulation," J. Acoust. Soc. Am., Vol. 34, 1962, pp. 1547-1552.
5. W. R. Klein, A General Treatment of Fraunhofer Light Diffraction by Ultrasonic Gratings, University Microfilms, Ann Arbor, 1964.
6. W. R. Klein, "Light Diffraction of Ultrasonic Beams of High Frequency near Bragg Incidence," presented at 5th International Congress of Acoustics, Liege, Belgium, 5 September 1965.

DISTRIBUTION LIST

DEPARTMENT OF DEFENSE

Office of the Director of Defense
Research & Engineering
Technical Library
Room 3C 128, Pentagon
Washington, D. C. 20301 (1)

Director
Advanced Research Projects Agency
ATTN: Director, Technical Information
Washington, D. C. 20301 (1)

Director
Weapons Systems Evaluation Group
Washington, D. C. 20305 (1)

Defense Intelligence Agency
Dissemination Center (DIAAQ-3)
Arlington Hall Station
Arlington, Virginia 22212 (2)

Defense Documentation Center
Cameron Station
ATTN: TISIA
Alexandria, Virginia 22314 (25)

DEPARTMENT OF THE ARMY

Office, Chief of Research and Development
Department of the Army
ATTN: Physical Sciences Division (CRD/O-P&E)
Washington, D. C. 20310 (1)

Commanding Officer
U. S. Army Personnel Research Office
ATTN: CRD-AI-DRL
Washington, D. C. 20315 (1)

Commanding Officer
U. S. Army Research Office-Durham
ATTN: CRD-AA-IP
Box CM, Duke Station
Durham, North Carolina 27706 (1)

Director of Research
HumRRO Division No. 5
(Air Defense) P. O. Box 6021
Fort Bliss, Texas 79916 (1)

Chief
U. S. Army Armor Human Research Unit
ATTN: Library
Fort Knox, Kentucky 40121 (1)

The Assistant Chief of Staff for Force
Development
Department of the Army
ATTN: Service Support Systems Division
Washington, D. C. 20310 (1)

Commanding Officer
U. S. Army Imagery Interpretation Center
Fort Holabird, Maryland 21219 (1)

Office of the Chief of
Communications-Electronics
Department of the Army
Washington, D. C. 20315
ATTN: CCEES-3a (1)

Major Commands

Commanding General
U. S. Army Materiel Command
ATTN: AMCSO-M
Washington, D. C. 20315 (1)

Commanding General
U. S. Army Materiel Command
ATTN: AMCRD-RP-E
Washington, D. C. 20315 (1)

Commanding Officer
U. S. Army Cold Regions Research and
Engineering Laboratory
Box 282
Hanover, New Hampshire 03755 (1)

Commanding Officer
Harry Diamond Laboratories
ATTN: Library
Washington, D. C. 20438 (1)

Commanding Officer
U. S. Army Human Engineering Laboratories
Aberdeen Proving Ground, Maryland 21005 (1)

Commanding General
U. S. Army Electronics Command
Fort Monmouth, New Jersey 07703 (30)

ATTN: AMSEL-CB	(1)
AMSEL-RD-GF	(1)
AMSEL-RD-MAT	(1)
AMSEL-RD-MAF	(2)
AMSEL-HL-CT-D	(1)
AMSEL-HL-CT-DT	(1)
AMSEL-HL-CT-A	(1)
AMSEL-HL-CT-RD	(2)
AMSEL-HL-CT-SD	(1)
AMSEL-HL-CT-L	(1)
AMSEL-HL-CT-I	(3)
AMSEL-HL-CT-P	(2)
AMSEL-HL-CT-O	(1)
AMSEL-HL-CT-R	(2)
AMSEL-NL-D	(3)
AMSEL-WL-D	(2)
AMSEL-KL-D	(3)
AMSEL-KL-EM	(1)
AMSEL-IO-T	(1)

Director
Night Vision Laboratory
U. S. Army Electronics Command
CS, NV & TA Laboratories
Fort Belvoir, Virginia 22060 (1)

Chief, Willow Run Office
Combat Surveillance & Target
Acquisition Lab, USAECOM
P. O. Box 618
Ann Arbor, Michigan 48107 (2)

Chief, Mountain View Office
Electronics Warfare Lab, USAECOM
ATTN: Technical Library
P. O. Box 205
Mountain View, California 94042 (1)

Chief
Intelligence Materiel Development Office
Electronics Warfare Lab.
Ft. Holabird, Maryland 21219 (1)

U. S. Army Electronics Command
Liaison Officer
Rome Air Development Center
ATTN: EMPL
Griffiss AFB, New York 13442 (1)

Commanding General
U. S. Army Missile Command
ATTN: AMSMI-DE
Redstone Arsenal, Alabama 35809 (2)

Commanding General
U. S. Army Missile Command
ATTN: Chief Document Section
Redstone Scientific Information Center
Redstone Arsenal, Alabama 35809 (2)

Director
U. S. Army Engineer Research & Development Lab
ATTN: STINFO Branch
Ft. Belvoir, Virginia 22060 (2)

Commanding Officer
Picatinny Arsenal
ATTN: SMUPA-DR7
Dover, New Jersey 07801 (1)

Commanding General
U. S. Army Electronics Proving Ground
ATTN: Technical Library
Fort Huachuca, Arizona 85613 (2)

Commanding Officer
Electronic & General Equipment Division
ATTN: Mr. Taragin (STEAP-DS-TF)
Aberdeen Proving Ground, Maryland 21005 (1)

President
U. S. Army Air Defense Board
Fort Bliss, Texas 79916 (1)

President
U. S. Army Artillery Board
ATTN: STEBA-GD
Fort Sill, Oklahoma 73504 (1)

President
U. S. Army Aviation Test Board
Fort Rucker, Alabama 36362 (1)

President
U. S. Army Infantry Board
ATTN: STEBC-SW
Fort Benning, Georgia 31905 (1)

Commanding General
U. S. Army Weapons Command
ATTN: AMSWE-RDR
Rock Island, Illinois 61202 (1)

Commanding General
U. S. Army Combat Developments Command
Experimentation Center
ATTN: CDEC-GC
Fort Ord, California 93941 (1)

Commanding Officer
U. S. Army Combat Developments Command
Experimentation Support Group
Fort Ord, California 93941 (2)

Commanding Officer
U. S. Army Combat Developments Command
Air Defense Agency
Ft. Bliss, Texas 79916 (2)

Commanding Officer
U. S. Army Combat Developments Command
Armor Agency
Fort Knox, Kentucky 40121 (1)

Commanding Officer
U. S. Army Combat Developments Command
Artillery Agency
ATTN: CAGAT-RT
Ft. Sill, Oklahoma 73504 (1)

Commanding Officer
U. S. Army Combat Developments Command
Communications-Electronics Agency
ATTN: CAGCE-M
Fort Monmouth, New Jersey 07703 (1)

Commanding Officer
U. S. Army Combat Developments Command
Engineer Agency
Fort Belvoir, Virginia 22060 (1)

Commanding Officer
U. S. Army Combat Developments Command
Infantry Agency
Fort Benning, Georgia 31905 (1)

Commanding Officer
U. S. Army Combat Developments Command
Intelligence Agency
Fort Holabird, Maryland 21219 (1)

Commanding General
U. S. Army Security Agency
ATTN: IACON
Arlington Hall Station
Arlington, Virginia 22212 (1)

Commanding General
U. S. Army Security Agency
ATTN: IACDA-OJ
Arlington Hall Station
Arlington, Virginia 22212 (1)

Commanding General
U. S. Army Security Agency
ATTN: IADEV-R
Arlington Hall Station
Arlington, Virginia 22212 (1)

Commanding General
U. S. Army Security Agency
ATTN: IATOP-E
Arlington Hall Station
Arlington, Virginia 22212 (1)

Schools

Commandant
U.S. Army Command & General Staff College
ATTN: Library Division
Fort Leavenworth, Kansas 66027 (1)

Commandant
U. S. Army Air Defense School
ATTN: AKBAAS-DR-R
Fort Bliss, Texas 79916 (4)

Commandant
U S. Army Artillery and Missile School
ATTN: AKPSITA
Fort Sill, Oklahoma 73504 (2)

Commandant
U.S Army Combat Surveillance School
Ft. Huachuca, Arizona 85613 (2)

Commandant
U.S. Army Engineer School
ATTN: AIBBES-SY
Fort Belvoir, Virginia 22060 (1)

Additional Army Agencies

Director
U.S. Army Engineer Geodesy, Intelligence and Mapping Research & Development Agency
ATTN: ENGGM-IN
Fort Belvoir, Virginia 22060 (1)

Director
U.S. Army Engineer Geodesy, Intelligence and Mapping Research & Development Agency
ATTN: ENGGM-TP
Fort Belvoir, Virginia 22060 (2)

Director
U.S. Army Engineer Geodesy, Intelligence and Mapping Research & Development Agency
ATTN: Chief, Photogrammetry Division
Fort Belvoir, Virginia 22060 (1)

U.S. Army Liaison Office
MIT-Lincoln Laboratory
Lexington, Massachusetts 02173 (2)

DEPARTMENT OF THE NAVY

Research Director
Office of Naval Research (Code 402)
Department of the Navy
Washington, D. C. 20360 (4)

Office of Naval Research (Code 463)
Department of the Navy
Main Navy Building, Room 4216
18th and Constitution Avenue, N.W.
Washington, D. C. 20360 (1)

Office of Chief of Naval Operations (Op-07TE)
Department of the Navy
ATTN: Technical Analysis and Advisory Group
Washington, D. C. 20350 (1)

Commander
U.S. Naval Oceanographic Office
ATTN: Library, Code 1640
Washington, D. C. 20390 (3)

Director
U.S. Naval Research Laboratory
ATTN: Code 2027
Washington, D. C. 20390 (2)

Commanding Officer
U. S. Naval Reconnaissance and Technical Support Center
4301 Suitland Board
Washington, D. C. 20390 (1)

Bureau of Naval Weapons (RRRE-31)
Department of the Navy
Washington, D. C. 20360 (1)

Chief, Bureau of Naval Weapons
ATTN: RTOS-311
Department of the Navy
Washington, D. C. 20360 (1)

Commanding Officer
U. S. Naval Ordnance Laboratory
ATTN: Library
Corona, California 91720 (1)

Commander
U.S. Naval Missile Center
Code N223 (Attn: A. Oster)
Space Research Division
Point Mugu, California 93041 (1)

Commander
U.S. Naval Ordnance Test Station
ATTN: Code 40508
China Lake, California 93557 (1)

Commander
U.S. Naval Ordnance Test Station
ATTN: Code 753
China Lake, California 93557 (1)

Chief, Bureau of Ships
Department of the Navy
ATTN: Code 680
Washington, D. C. 20360 (1)

Commanding Officer and Director
U.S. Navy Electronics Laboratory
ATTN: Library
San Diego, California 92152 (1)

Commanding Officer and Director (Code 222A)
U. S. Naval Radiological Defense Laboratory
San Francisco, California 94135 (1)

DEPARTMENT OF THE AIR FORCE

Headquarters
Research & Technology Division
Bolling Air Force Base
ATTN: RTTC
Washington, D. C. 20332 (1)

Director
Air Force Avionics Laboratory
ATTN: AFAL(AVRS/R. R. Roalef)
Wright-Patterson Air Force Base, Ohio 45433 (1)

Director
Air Force Avionics Laboratory
ATTN: AVNT (Mr. K. H. McCoin)
Wright-Patterson Air Force Base, Ohio 45433 (2)

Director, Air Force Avionics Laboratory
ATTN: AVRS/Capt. R. L. Grossel
Wright-Patterson AFB, Ohio 45433 (1)

Commander
Foreign Technology Division
ATTN: TDAT
Wright-Patterson Air Force Base, Ohio 45433 (2)

Director
Research and Technology Division
ATTN: SEG (SEST) Mr. David Egan
Wright-Patterson AFB, Ohio 45433 (1)

Commander
Rome Air Development Center
ATTN: Shelton MacLeod/EMI
Griffiss AFB, New York 13442 (1)

Commander
Rome Air Development Center
ATTN: M. A. Diab (EMASS)
Griffiss AFB, New York 13442 (1)

Commander
Rome Air Development Center
ATTN: Mr. J. A. Lovecchio (EMATS)
Griffiss AFB, New York 13442 (1)

Commander
Rome Air Development Center
ATTN: Documents Library (EMLAL-1)
Griffiss AFB, New York 13442 (1)

Commander
APGC (AFL-2825)
Eglin AFB, Florida 32542 (1)

Commander
U.S. Air Force Tactical Air Reconnaissance Center
Director of Intelligence (DRI)
ATTN: TARC Technical Library, AFL #4816
Shaw Air Force Base, South Carolina 29152 (1)

Commander
ESD/ESTI
L. G. Hanscom Field
Bedford, Massachusetts 01731 (2)

Commander
544 Aerospace R Tech Wg (CAS)
Offutt AFB, Nebraska 68113 (1)

Commander
Tactical Air Command (OA)
Langley AFB, Virginia 23365 (1)

Director
Air University Library
ATTN: AUL3T-7971
Maxwell AFB, Alabama 36112 (1)

U.S. MARINE CORPS

Director
Marine Corps Landing Force Development Center
Marine Corps Schools
Quantico, Virginia 22134 (2)

ADDITIONAL GOVERNMENT AGENCIES

Central Intelligence Agency
ATTN: OCR-DD/Std. Dist.
Washington, D. C. 20505 (4)

National Aeronautics and Space Administration
Manned Spacecraft Center
ATTN: Tech Infor Dissemination Branch
Houston, Texas 77058 (2)

NASA Scientific & Technical Information Facility
ATTN: Acquisitions Branch (S-AK/DL)
P.O. Box 33
College Park, Maryland 20740 (2)

MISCELLANEOUS ORGANIZATIONS

Applied Physics Laboratory
The Johns Hopkins University
ATTN: Documents Librarian
8621 Georgia Avenue
Silver Spring, Maryland 20910 (2)

THRU: U.S. Army Procurement Office
9800 Savage Road
Fort George Meade, Maryland 20755

TO: Syracuse University Research Corporation
P.O. Box 26, University Station
ATTN: Electronic Research Lab
Syracuse, New York 13210 (2)

THRU: The Rome Air Development Center (EMR)
Griffiss Air Force Base
Rome, New York 13442

TO: Syracuse University Research Corporation
P. O. Box 26, University Station
ATTN: Special Projects Laboratory
Syracuse, New York 13210 (1)

THRU: Resident Office Headquarters
Los Angeles Contract Management District
United States Air Force
The RAND Corporation
Santa Monica, California 90406

TO: The RAND Corporation
1700 Main Street
ATTN: Library
Santa Monica, California 90406 (1)

Institute for Defense Analyses
ATTN: Classified Library
400 Army-Navy Drive
Arlington, Virginia 22202 (2)

Remote Area Conflict Information Center
Battelle Memorial Institute
505 King Avenue
Columbus, Ohio 43201 (1)

Remote Area Conflict Information Center
Battelle Memorial Institute
1755 Massachusetts Avenue, N.W.
Washington, D. C. 20036 (1)

THRU: Commanding Officer
Research & Technology Division
Wright-Patterson AFB, Ohio 45433
ATTN: SEG/SEAEA

TO: Cornell Aeronautical Laboratory, Inc.
4455 Genesee Street
ATTN: J. P. Desmond, Librarian
Buffalo, New York 14221 (2)

THRU: U. S. Army R&D Operations Research Advisory Group
Research Analysis Corporation
McLean, Virginia 22101

TO: Research Analysis Corporation
ATTN: Library
McLean, Virginia 22101 (1)

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Willow Run Laboratories, Institute of Science and Technology The University of Michigan, Ann Arbor	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE
NONPERPENDICULAR ILLUMINATION OF ULTRASONIC CELLS

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Summary

5. AUTHOR(S) *(Last name, first name, initial)*
Henry, Edwin E. and Ring, Harvey

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
August 1966	viii + 14	6

8a. CONTRACT OR GRANT NO. DA-28-043-AMC-00013(E) b. PROJECT NO. 1P6 20801 A 175 c. Task 05 d.	9a. ORIGINATOR'S REPORT NUMBER(S) 6400-66-T 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* 7000-34-T, ECOM-00013-66

10. AVAILABILITY/LIMITATION NOTICES
Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
Cosponsored by and also published for the U. S. Air Force under Contract AF 33(615)-1452 (see 9b above).	Willow Run Office CS & TA Laboratory, USAECOM Box 618, Ann Arbor, Mich. 48107

13. ABSTRACT
Results obtained by nonperpendicular illumination of ultrasonic cells are described. There is reasonably good agreement between theory and experiment; this agreement exists for results obtained when the cell is operated at 5, 15, and 25 Mc/s. In an optical analog computer, the light intensity of the optical output can be increased considerably by illuminating the cell at the Bragg angle; but this increase is obtained at the expense of decreased bandwidth of operation.

DD FORM 1 JAN 64 1473

Security Classification

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Mathematics and data processing						
Computers and data systems						
Analog computers						
Optical analysis						
Diffraction						
Spectrum analyzers						
Ultrasonic radiation						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2*a*. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2*b*. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7*a*. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7*b*. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8*a*. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8*b*, 8*c*, & 8*d*. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9*a*. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9*b*. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through ________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through ________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through ________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.

Security Classification